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GEOLOGY.—*Placer gold in Alaska.*[1] J. B. MERTIE, JR., U. S. Geological Survey.

The study of metalliferous placers, if pursued in its many aspects, is a very comprehensive one, because it leads directly into several branches of geology and indirectly into the fields of mineralogy, metallography, inorganic and physical chemistry and allied topics. A lode of some sort must necessarily have existed before a placer could be formed. Therefore the local bedrock geology is of primary interest, and its investigation calls for petrographic work and possibly the study of ore deposits. But usually neither the rocks nor the ores now exposed at the surface are exactly like those that existed at the time when the placers were formed, so that an understanding of surficial geologic processes is also required not merely to interpret the preexisting bedrock geology, but more particularly to decipher the history and mode of accumulation of the placers. Yet physiography and the related surficial earth sciences do not always suffice, because the metals contained in many placers were liberated from their bedrock sources long before the present surficial features originated. Hence stratigraphy and paleontology not infrequently constitute another part of the investigation. It is hardly necessary to add that structural geology is likewise an essential topic, because the structure of bedrock is an important factor in all geomorphic interpretations. And finally, certain of the more specialized branches of geology and geophysics may enter into the investigation.

By these remarks it is not intended to imply that the writer has made any such comprehensive studies. Unfortunately many reasons exist why the gold placers of Alaska have not received such treatment, and not the least of these is that the time allocated to such work, both in the field and in the office, has been inadequate for investigations of such an extended scope. Nevertheless, even casual field examination and limited laboratory work, when extended over a considerable pe-

[1] Address of the retiring president of the Geological Society of Washington, delivered December 13, 1939. Published by permission of the Director, Geological Survey, United States Department of the Interior. Received January 12, 1940.

riod of years, lead to the formulation of more or less definite ideas; and, though such ideas merely point the way toward future investigations, they may be worthy of statement.

PHYSICAL AND CHEMICAL PROPERTIES OF GOLD-SILVER ALLOYS

The physical and chemical data presented below are in no sense intended to be a compendium of the mineralogy, physics, and chemistry of gold and silver, as an ordinary volume would not suffice to cover such a vast field. Instead there will be given certain disconnected but significant data that seem to bear upon the origin and accumulation of placer gold.

Pure gold has not been found in nature. Instead, it is always alloyed with more or less silver, together with a small proportion of base metals, mainly copper and iron, which collectively are designated as the dross. Gold has been found alloyed with some of the platinum metals; and other specialized species, such as alloys of gold and bismuth, and natural amalgam have also been described. The purest free gold that I have been able to find any record of is a sample of lode gold from the Great Boulder Mine, in the Kalgoorlie district of Western Australia, which had a fineness of 999.1 parts gold in a thousand; but several samples from the Cripple Creek district are recorded as having finenesses of 999. Most of the Australian gold is exceptionally high grade, yet the quartz veins of the Wiluna area, of Western Australia, have produced the lowest grade of natural gold on record, ranging in fineness from 400 to 580 parts gold in a thousand, the remainder being mainly silver. Native silver is relatively uncommon,

TABLE 1.—FINENESS OF PLACER GOLD IN ALASKA

Fineness (parts gold per thousand)	Number of samples	Fineness (parts gold per thousand)	Number of samples
975–965	4	795–785	27
965–955	13	785–775	28
955–945	33	775–765	21
945–935	6	765–755	17
935–925	16	755–745	12
925–915	47	745–735	4
915–905	115	735–725	9
905–895	122	725–715	6
895–885	127	715–705	1
885–875	104	705–695	2
875–865	119	695–685	0
865–855	166	685–675	1
855–845	125	675–665	1
845–835	101	665–655	0
835–825	143	655–645	0
825–815	79	645–635	1
815–805	37	635–625	1
805–795	39	625–615	1

and is usually free of gold. The placer gold so far mined in Alaska ranges in fineness from 620 to 973 parts gold in a thousand. Philip S. Smith[2] has recently compiled from the files of the U. S. Geological Survey 1,528 assays of the placer gold alloys that have been mined in Alaska. Seven additional assays, showing finenesses of less than 620, are also on record from the Territory, but these are considered probably to represent bullion that included man-made impurities such as lead shot, solder, and other such materials. This record is presented in Table 1.

The above data are also presented in the form of a frequency curve in Fig. 1. The graph was prepared by C. E. Van Orstrand and H. C. Spicer, both of the U. S. Geological Survey. The following statement, prepared by Mr. Van Orstrand, gives the essential facts bearing upon the choice of an interpolation formula, and a summary of the computations.

The equation, $y=ax^m e^{-b_2 x^n}(b_0+b_1 x+b_2 x^2)$ ..... (1)
is here used primarily as an interpolation formula. In this equation, x represents the series of integers, 1,2,3, . . . beginning with 1 at 970.

The equation, $y=ax^m e^{-b_2 x^n}$ ..... (2)
has been used to represent production curves in the oilfields expressed as a function of the time.[3] Calculation of the coefficients in (1) has been made by first evaluating the constants in (2) and then multiplying the computed values of (2) by $(b_0+b_1 x+b_2 x^2)$ and solving the product relation equated to the observed values of y for the values of b_0, b_1, and b_2. All the adjustments were made by the method of least squares.

The results of the calculations show that the sum of the observed values (Σy_0) is 1,524; that of the computed values (Σy_c) is 1,493. The sum of the squares of the residuals (Σv^2) is 8,423. The first two quantities can be brought into closer agreement, and the last one can be reduced somewhat by making a more precise determination of n. The modal frequency is $x=11.11$, or, in terms of fineness, 868.9. The computations involved in obtaining this graph were performed by Mr. Spicer.

The histogram shown in Fig. 1 may possibly suggest to the reader that a less regular curve is justified by the numerical data. But the 1,528 assays, upon which this figure is based, are in reality only a small part of the thousands of assays known to have been made upon the placer golds of Alaska. Hence the irregularity of the histogram is interpreted as a condition due entirely to imperfect sampling, and not to any physical-chemical relationship that might be shown in an equilibrium diagram. For this reason, a probability curve is believed to be the best method of representing the available data.

[2] SMITH, PHILIP S. *Fineness of gold from Alaska placers.* U. S. Geol. Surv. Bull. 910: in preparation.

[3] VAN ORSTRAND, C. E. *On the empirical representation of certain production curves.* Journ. Washington Acad. Sci. 15(2): 19–33. Jan. 19, 1925.

From this graph it appears probable that the placer gold alloys most commonly mined in Alaska have a fineness of about 870 parts gold in a thousand. As the dross seldom exceeds 1 percent, it follows that the corresponding content of silver is about 120 parts per thousand. One of the most significant features of these data, concerning which more will later be said, is the absence in Alaska or elsewhere in the world of placer gold alloys of a fineness much less than 600; and

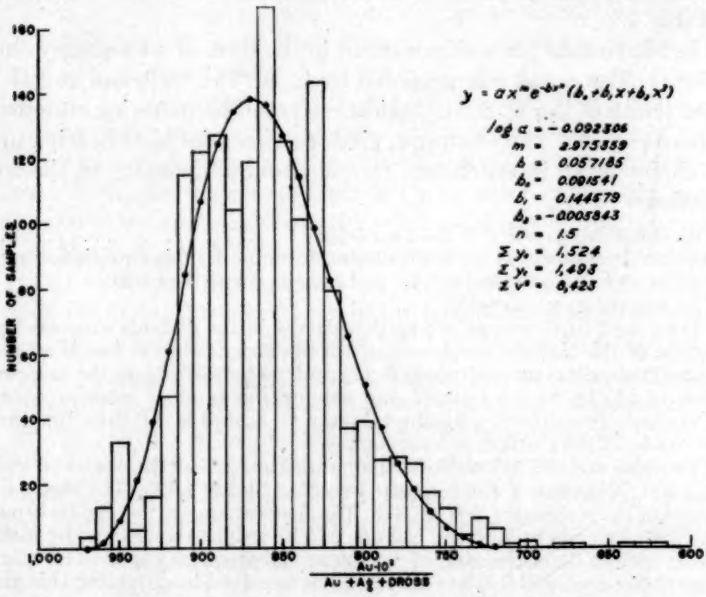


Fig. 1.—Frequency curve, showing fineness of placer gold in Alaska.

also the world-wide absence of any gold-silver alloys having a fineness of less than 400.

One of the most ill-defined terms applied to natural gold alloys is the term electrum. According to Rose and Newman,[4] electrum means pale yellow natural alloys of gold and silver containing 15 to 35 percent of silver; but Dana[5] mentions two species of electrum containing over 38 percent of silver; whereas Lindgren[6] restricts electrum to an alloy containing 50 percent of silver. According to the first definition,

[4] ROSE, Sir THOMAS K., and NEWMAN, W. A. C. *The metallurgy of gold*, ed. 7, p. 46. 1937.
[5] DANA, JAMES W. *The system of mineralogy*, ed. 6, p. 15. 1914.
[6] LINDGREN, WALDEMAR. *Mineral deposits*, ed. 2, p. 229. 1919.

if 1 percent of the alloy is allocated to dross, all natural gold alloys in the range of fineness between 840 and 640 parts gold in a thousand should be classified as electrum; and therefore about one-third of the natural gold alloys of Alaska are electrum. If the pale yellowish color is an indispensable part of the definition, many of the Alaskan alloys, in the range from 840 to 640 fineness, are not necessarily electrum. An increasing percentage of silver does modify the color of a gold-silver alloy, and the color of an artificial alloy containing 50 percent of silver is actually a faint yellowish white. But I suspect that the natural alloys that the ancients designated as electrum owed their pale color as much to elements of the dross as to their content of silver. Therefore, although the term electrum is of historical interest, it does not seem that it belongs in a handbook of mineralogy as a species or variety of the natural gold alloys, unless it is given a more exact chemical definition than it now has.

Many elements, usually in small quantities, have been found to form a part of the natural gold-silver alloys. Such accessory metals usually constitute from a half of 1 percent to 1 percent of the alloys. Copper and iron are the principal metals of the dross, but the ratio of these two elements to one another is extremely variable, such that either of them may preponderate greatly over the other. Yet a summation of the chemical analyses of gold, given by Hintze,[7] shows that the average quantities of copper and iron in the natural gold-silver alloys, is nearly equal. Small quantities of a number of other elements have also been detected in placer gold by chemical analysis, and doubtless traces of still others may be found by spectrographic analysis. The principal accessory metals that have been recognized by chemical analysis of the natural gold-silver alloys, are zinc, mercury, tin, lead, antimony, bismuth, nickel, cobalt, rhodium, palladium, iridium, and platinum; and of these all but antimony, bismuth, cobalt, and rhodium have been identified chemically in the placer golds of Alaska.

The physical properties of the natural alloys of gold and silver, ordinarily designated as free gold, are given scant consideration in books on mineralogy and economic geology; and some quite erroneous statements have been published. Thus in a recently published handbook it is stated that "gold is a yellow malleable metal with a specific gravity from 15.6 to 19.3, and a melting point at about 1,062° C." Pure gold does have the melting point stated, but its specific gravity

[7] HINTZE, CARL. *Handbuch der Mineralogie* 1: 316–320. 1904.

is not to any considerable degree variable, being approximately 19.3 to the nearest digit in the first decimal place. And if the author's description referred to natural gold alloys of variable composition, then their melting points were not 1,062° C. Moreover, natural alloys of gold and silver are known that have specific gravities as low as 12.5 instead of 15.6. Hence the whole statement is erroneous.

The physical properties of gold and silver are well known and are carefully tabulated in reference books such as the International Critical Tables. But in this paper it is the natural alloys of gold and silver, rather than the pure metals, that are being discussed. Therefore, for present purposes, the following short tabulation of the physical properties of pure gold and pure silver will suffice:

TABLE 2.—PHYSICAL PROPERTIES OF GOLD AND SILVER

Property	Gold	Silver
Atomic weight	197.2	107.9
Specific gravity	19.3	10.5
Melting point (°C)	1063°	960°
Boiling point (°C)	2600°	1950°
Hardness (Moh's scale)	2.5	3.0
Electrical resistivity. Ohms per cm³ at 20° C.	2.4×10^{-6}	1.6×10^{-6}
Magnetic susceptibility (mass unit) at 18° C.	-0.15×10^{-6}	-0.20×10^{-6}
Thermal coefficient of linear expansion at 20° C.	14.2×10^{-6}	18.9×10^{-6}
Crystallography	Face-centered cubic space lattice.	Face-centered cubic space lattice.
Length of side of cubic lattice (cm)	4.07×10^{-8}	4.08×10^{-8}
Atomic radius (cm)	1.44×10^{-8}	1.44×10^{-8}
Workability	Very malleable and ductile.	Very malleable and ductile, but less so than gold.

Placer golds are well known to be natural alloys, principally of gold and silver, but judging from published descriptions little is known of their true nature. Much investigative work, to be sure, has been done on artificial alloys of different metals, including gold and silver, but even this information does not appear in our textbooks on mineralogy. In dry melts, gold and silver are continuously miscible in all proportions, like alcohol and water, and remain so after solidification, forming a solid solution analogous to albite and anorthite. Raydt[8] has studied the binary system of gold and silver, and has derived an equilibrium diagram, relating composition to temperature, which is shown in Fig. 2.

This diagram shows continuous solidus and liquidus curves, without maximum or minimum points. It should also be emphasized that

[8] RAYDT, U. *Über Gold-Silberlegierungen.* Zeitschr. anorg. Chemie **75**: 58–62. 1912.

gold and silver, as well as all other metals that have solidified from dry melts, exist as crystallites, usually in allotriomorphic aggregates. These crystallites, in any one alloy, do not necessarily have the same chemical composition; nor, in fact, is any one crystallite necessarily chemically homogeneous.

Copper and iron, however, the principal metals of the dross, behave differently, when melted with gold and silver. Copper, for example, is miscible in all proportions in the liquid state, either with gold or with silver, and forms a solid solution with gold in the solid state; but copper and silver have limited ranges of miscibility in the solid state, from 0 to 5 percent and from 95½ to 100 percent copper. Iron, on the

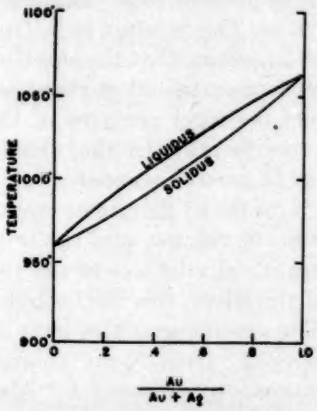


Fig. 2.—Equilibrium diagram for artificial gold-silver alloys.

other hand, shows unlimited miscibility with gold in the liquid state, but complete immiscibility with silver; and in the solid state, alpha iron at 20° C shows solid solution with gold in the ranges from 0 to 20 percent, and 82 to 100 percent iron, whereas with silver iron is completely immiscible in the solid state.

The phase relations shown by Raydt's equilibrium diagram, and additional phase relations known to exist between binary and ternary systems of gold, silver, copper, iron, and other elements studied in artificial melts, do not necessarily hold for natural alloys, because the effects of still other components, such as quartz, water, base metals, and the so-called mineralizers have not been evaluated. It seems likely, however, that the relationship observed in dry melts will in some measure, perhaps in large measure, apply to the natural alloys of gold and silver; and for this reason placer gold should be considered

to be altogether or in large part a solid solution of crystalline gold and silver, with small quantities of other metals, in unknown phase relationships. Yet certain significant differences between natural and artificial alloys have been observed, which seem worthy of emphasis.

If any two metals were completely immiscible in the solid state, so that they solidified as individual grains in a eutectic or mechanical mixture, it should be possible from a chemical analysis to compute those physical properties such as specific gravity, which are functions of additive quantities like mass and volume. But gold and silver crystallize from dry melts as solid solutions, or, if you will, as atomic mixtures; and if the natural alloys of gold and silver are likewise solid solutions, it should not be possible from chemical data alone to compute their specific gravities. This is found to be true. But it is a matter of considerable interest to assume that the eutectic relationship holds, and to compute, either from artificial mixtures of known weights of gold and silver or from chemical analyses of the natural alloys of these two metals, the specific gravities that should result. These theoretical values can then be used as standards, with which to compare the respective alloys, in order to determine whether the latter show contraction or expansion in volume, and the order of such changes, as compared with mechanical mixtures of the two components. For artificial alloys of gold and silver, this has been done by Matthiessen[9] and by Hoitsema.[10] The specific gravities have also been computed theoretically by McKeehan[11] from X-ray analysis.

The molecular composition indicated by Matthiessen and McKeehan were converted to percentages of gold and silver by weight, to correspond with the form of the ratios given by Hoitsema. From these ratios, and from the specific gravities of the pure gold and pure silver used by these three men, the specific gravities and specific volumes were then computed, which should exist if the two components were mechanically mixed. The differences between these specific volumes, and those found by actual measurement or by X-ray analysis, were then compared, giving a column of differences which show whether volumetric contraction or expansion took place. All these data are shown in Tables 3–5.

An adjusted graph of the specific gravities, utilizing the data of Matthiessen, Hoitsema, and McKeehan has been published in the

[9] MATTHIESSEN, A. *On the specific gravity of alloys.* Philos. Trans. Roy. Soc. London **150**: 183. 1859.

[10] HOITSEMA, C. *Die Dichte von Goldkupfer und Goldsilberlegierungen.* Zeitschr. anorg. Chemie **41**: 66–67. 1904.

[11] MCKEEHAN, L. W. *The crystal structure of silver-palladium and silver-gold alloys.* Phys. Rev. (ser. 2) **20**: 429. 1922.

TABLE 3.—SPECIFIC GRAVITIES AND SPECIFIC VOLUMES OF ARTIFICIAL ALLOYS

Composition[1]	Spec. Grav.[2] (true)	Spec. Grav. (computed)	Spec. Vol. (true)	Spec. Vol. (computed)	Spec. Vol. (differences)
Au.....	19.265				
Au_6Ag.....	18.041	17.999	0.05543	0.05556	+0.00013
Au_4Ag.....	17.540	17.493	.05701	.05717	+ .00016
Au_2Ag.....	16.354	16.315	.06115	.06129	+ .00014
AuAg.....	14.870	14.847	.06725	.06735	+ .00010
$AuAg_2$.....	13.432	13.383	.07445	.07472	+ .00027
$AuAg_4$.....	12.257	12.215	.08159	.08187	+ .00028
[3]$AuAg_6$.....	11.760	11.715	.08503	.08536	+ .00033
Ag.....	10.468				

[1] Atomic weights of 197 and 108 were used by Matthiessen in determining the percentages of gold and silver in the specified alloys.
[2] Specific gravity determinations by A. Matthiessen.
[3] Owing to a typographic error, this reads $AuAg_3$ in the original paper.

TABLE 4.—SPECIFIC GRAVITIES AND SPECIFIC VOLUMES OF ARTIFICIAL ALLOYS

Parts per thousand		Spec. Grav.[1] (true)	Spec. Grav.[2] (computed)	Spec. Vol. (true)	Spec. Vol. (computed)	Spec. Vol. (differences)
Au	Ag					
1000	0	19.26	———	———	———	———
917	83	18.08	18.000	.05531	.05556	+0.00025
843	157	16.96	17.009	.05896	.05879	− .00017
750	250	16.03	15.907	.06238	.06287	+ .00049
667	333	15.07	15.038	.06636	.06650	+ .00014
583	417	14.24	14.250	.07023	.07018	− .00005
500	500	13.60	13.549	.07353	.07381	+ .00028
417	583	13.00	12.913	.07692	.07744	+ .00042
333	667	12.38	12.328	.08070	.08112	+ .00042
250	750	11.78	11.799	.08489	.08475	− .00014
167	833	11.28	11.314	.08861	.08839	− .00022
0	1000	10.45	———	———	———	———

[1] Specific gravity determinations by C. Hoitsema.
[2] A number of corrections were made in the specific gravities and specific volumes computed by Hoitsema.

TABLE 5.—SPECIFIC GRAVITIES AND SPECIFIC VOLUMES OF ARTIFICIAL ALLOYS

Composition[1]	Spec. Grav.[2] (X-ray)	Spec. Grav. (computed)	Spec. Vol. (X-ray)	Spec. Vol. (computed)	Spec. Vol. (differences)
Au.....	19.24	———	———	———	———
Au_6Ag.....	18.24	18.365	.05482	.05445	−0.00037
Au_4Ag.....	17.44	17.490	.05734	.05718	− .00016
Au_3Ag_2.....	16.06	16.615	.06227	.06019	− .00208
Au_2Ag_3.....	15.31	15.740	.06523	.06353	− .00179
AuAg.....	14.74	14.865	.06784	.06727	− .00057
Au_2Ag_3.....	13.50	13.990	.07407	.07148	− .00259
$AuAg_4$.....	11.93	12.240	.08382	.08170	− .00212
Ag.....	10.49	———	———	———	———

[1] Atomic weights of 197.2 and 107.88 were used by McKeehan in determining the percentages of gold and silver in the specified alloys.
[2] X-ray observations and derived specific gravities by L. W. McKeehan.

International Critical Tables.[12] This, with some corrections, is shown in Fig. 3.

[12] *International critical tables of numerical data: Physics, chemistry and technology* **2**: 590. 1927.

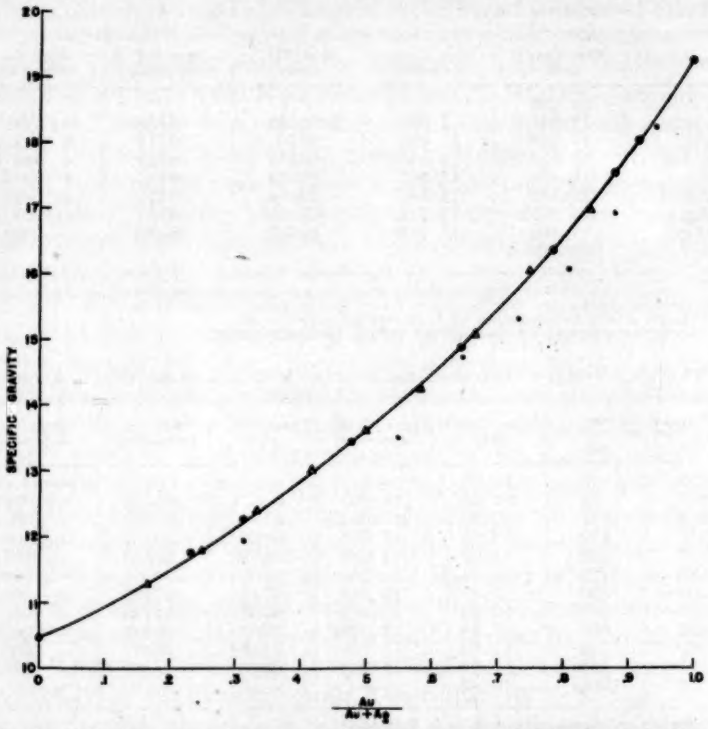


Fig. 3.—Adjusted curve, showing specific gravities of artificial gold-silver alloys as obtained by Matthiessen⊙, Hoitsema△, and McKeehan●.

The computation of the specific gravity of a binary alloy from its chemical composition, if the two components are considered to be mechanically mixed, is simply done by means of the following formula:

$$S = \frac{M_1 + M_2}{V_1 + V_2} = \frac{M_1 + M_2}{\frac{M_1}{S_1} + \frac{M_2}{S_2}} = \frac{(M_1 + M_2)\, S_1 S_2}{M_1 S_2 + M_2 S_1}$$

where M_1 and M_2 are the weights, and S_1 and S_2 are the corresponding specific gravities of the two components. To compute the specific gravity of a n-ary alloy from its chemical composition, upon the assumption that all the components are mechanically mixed, the above formula has been expanded to read as follows:

$$S = \frac{(M_1 + M_2 + M_3 + \cdots + M_n)\,(S_1 S_2 S_3 \cdots S_n)}{(M_1 S_2 S_3 S_4 \cdots S_n) + (M_2 S_1 S_3 S_4 \cdots S_n) + (M_3 S_1 S_2 S_4 \cdots S_n) + \cdots}.$$

$$\cdots + (M_{n-2}S_1S_2 \cdots S_{n-3}S_{n-1}S_n) + (M_{n-1}S_1S_2 \cdots S_{n-3}S_{n-2}S_n) + \frac{1}{+ (M_nS_1S_2 \cdots S_{n-3}S_{n-2}S_{n-1})}}}$$

Now let us apply this formula to four complete chemical analyses of placer gold alloys from Alaska, which have recently been made in the laboratory of the U. S. Geological Survey. These are presented in Table 6.

TABLE 6.—ANALYSES OF PLACER GOLD FROM ALASKA

Constituent	1	2	3	4
Gold	83.90	80.59	87.53	92.69
Silver	10.42	18.21	11.12	6.16
Platinum	.01	.20	.28	.42
Iridium		.02	.05	trace
Palladium			trace	
Lead		.06	.07	.08
Mercury		.10	.05	.02
Iron	1.02	.08	.07	.07
Nickel	.007			
Copper	.002	.03	.01	.04
Zinc		.04	.03	.01
Tin		trace	trace	trace
SiO_2		.43	.40	.77
SiO_2, Al_2O_3, and Cr_2O_3	.432			
Insoluble in aqua regia	1.67			
Totals	97.461	99.76	99.61	100.26

1. Squirrel Creek, Goodnews Bay district, southwestern Alaska. E. T. Erickson, analyst.
2. Seventymile River, Eagle district, east-central Alaska. R. E. Stevens, analyst.
3. Fourth of July Creek, Eagle district, east-central Alaska. R. E. Stevens, analyst.
4. Woodchopper Creek, Circle district, east-central Alaska. R. E. Stevens, analyst.

When the specific gravities of these four samples are computed, upon the assumption and with the formula above given, some anomalous results appear. These are given in Table 7.

TABLE 7.—SPECIFIC GRAVITIES AND SPECIFIC VOLUMES OF PLACER GOLD FROM ALASKA

Sample No.	Spec. Grav. (true)	Spec. Grav. (computed)	Spec. Vol. (true)	Spec. Vol. (computed)	Spec. Vol. (differences)
1	13.32	17.43	0.07508	0.05737	−0.01771
2	15.18	16.69	.06588	.05992	− .00596
3	16.00	17.61	.06250	.05679	− .00571
4	15.87	18.31	.06301	.05461	− .00840

The experimental work by Matthiessen shows that when pure gold and pure silver are melted together in definite proportions, there results a contraction in volume of small magnitude, regardless of the proportions of the two metals. Hoitsema's results show both a con-

traction and an expansion of volume, for different compositions, but the differences between the true and computed specific gravities are at least of the same order of magnitude as those found by Matthiessen. The results obtained from McKeehan's data are not strictly comparable with those obtained by Matthiessen and Hoitsema but are given for the sake of comparison. When the same computations are made from chemical analyses of placer golds, as shown above, there results an expansion in volume, of large and variable magnitude. Parenthetically it may be added that sample no. 1 is held by a strong electromagnet, although both gold and silver are diamagnetic. The reason for these differences between the artificial and natural alloys of gold and silver is not known, but there seem to be ample grounds for suspecting that complex phase relationships may exist. If this is true, a careful study of placer gold by physical and chemical methods is needed, in order to discover the present compositions of such alloys, both in bulk and in crystallites or grains of microscopic dimensions. A knowledge of the present physical and chemical conditions of these alloys should also lead to a better understanding of the temperatures, pressures and other conditions that existed in gold-quartz veins at the time of their formation.

The solubilities of the natural alloys of gold and silver in inorganic acids also have a bearing upon their occurrence in nature, both in their bedrock habitats and in their subsequent occurrence in placers. Gold is not appreciably attacked by any single acid except selenic acid (H_2SeO_4), but it dissolves readily in solutions generating the nascent halides, and therefore in aqua regia. Silver, on the other hand, is dissolved by boiling concentrated sulphuric acid, by dilute nitric acid and by hydriodic acid, and is attacked by all the halides, by warm selenic acid, and to a very slight extent by hydrochloric acid in the presence of oxidizing agents. Silver has also been shown to be slightly soluble in distilled water, to the extent of 3.7×10^{-5} grams per liter. But just as the physical properties of the alloys of gold and silver can not be directly inferred from the physical properties of the two pure components, so the solubilities of these alloys are not linear functions of the solubilities of pure gold and silver.

One profitable line of investigation in connection with the study of gold placers would be a study of the solubilities of artificial and natural gold-silver alloys in the inorganic acids and other solvents that might be expected to occur in surface and ground waters. At present the most suggestive fact of this sort results from the well-known process of quartation, or inquartation (as it is sometimes

called), which has been used for over 600 years for parting silver from gold-silver alloys. Natural gold alloys are not attacked either by nitric or sulphuric acids, but if a sufficient amount of silver is added to the alloy, practically all the silver can then be dissolved by nitric acid at a temperature of 115° F. Essentially the same result is obtained by the use of sulphuric acid. The really interesting feature, however, is the fact of the limits of partial and complete solubility; and these are shown in the accompanying diagram, taken from Tammann's[13] work. (See Fig. 4.)

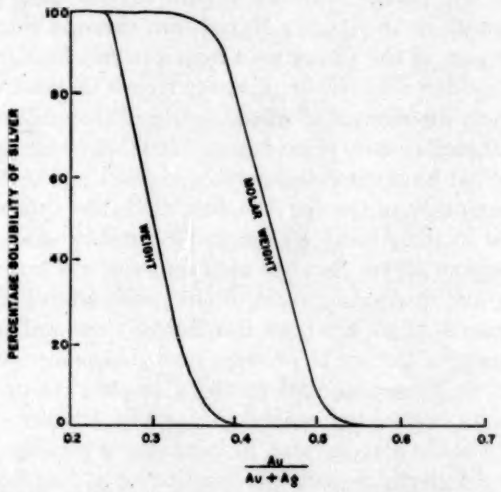


Fig. 4.—Sketch showing amounts of silver dissolved by nitric acid from artificial gold-silver alloys.

The fact particularly to be noted in this diagram is that no silver can be dissolved by inorganic acids from an artificial gold-silver alloy having the general composition of placer gold, because the high content of gold renders them practically insoluble. What would be the probability, then, that any appreciable amount of silver could be dissolved from placer gold by cold surface waters? Further reference will later be made to this topic.

GEOGRAPHIC DISTRIBUTION OF GOLD PLACERS IN ALASKA

It is not the purpose of this paper to tabulate and describe the gold placers of Alaska, though such a compilation might indeed be a useful

[13] TAMMANN, GUSTAV. *A textbook of metallography*, ed. 3, p. 314. 1925. (Translated from the German by R. S. Dean and L. G. Swenson.)

piece of work. Instead, the writer aims principally to point out the known facts that have a bearing upon the origin and accumulation of such placers; and in order to accomplish this objective, geographic references will be made only secondarily.

The principal fact to be noted regarding the geographic distribution of gold placers in Alaska is that all the really important deposits occur in the unglaciated part of the Territory. (See Fig. 5.) This unglaciated placer-bearing region lies north of the Alaska Range, south of the Brooks Range, and extends westward and southwestward to the Arctic Ocean and Bering Sea.[14] To be sure, several small placer camps are located south of the Alaska Range, but these in toto produce no considerable part of the placer gold mined in Alaska. Granitic rocks, which are considered to be the ultimate source of most of the placer gold, are widely distributed in Alaska south of the crest of the Brooks Range, and therefore no a priori reason exists why lode and placer deposits should not have coexisted north and south of the Alaska Range before the beginning of the Ice Age, and doubtless this was true. But glacial action in the Alaska Range and coastal ranges, and seaward therefrom, was so severe that the country rock was largely denuded, thus eroding and dissipating most of the pre-Quaternary alluvial deposits. In general, there has been insufficient time and erosive action since the retreat of the ice to produce new gold placers from bedrock sources. But at some localities in the glaciated regions, auriferous glacial deposits have been reconcentrated by Recent streams, thus producing workable placers; and, in fact, at one locality in the Cache Creek district, a glacial deposit has constituted a low grade placer. At other localities in southern Alaska there remain remnants of preglacial placers, which were located in valleys that were transverse to the principal flow lines of the ice, or were otherwise protected from glacial scour. These explainable exceptions in no way vitiate the general rule that the important placers are restricted to the unglaciated part of Alaska.

Most of the workable gold lodes, however, lie south of the Alaska Range, or in southeastern Alaska southwest of the Coast Range, though a number of small gold lodes have been discovered and are being mined in the unglaciated region of interior Alaska. The meaning of this distribution of the gold lodes is less apparent, but it is possible that the denudation of bedrock by glaciation has been an important factor favoring the discovery of lodes in southern and south-

[14] CAPPS, STEPHEN R. *Glaciation in Alaska*. U. S. Geol. Surv. Prof. Paper 170-A, pl. 1, 1931.

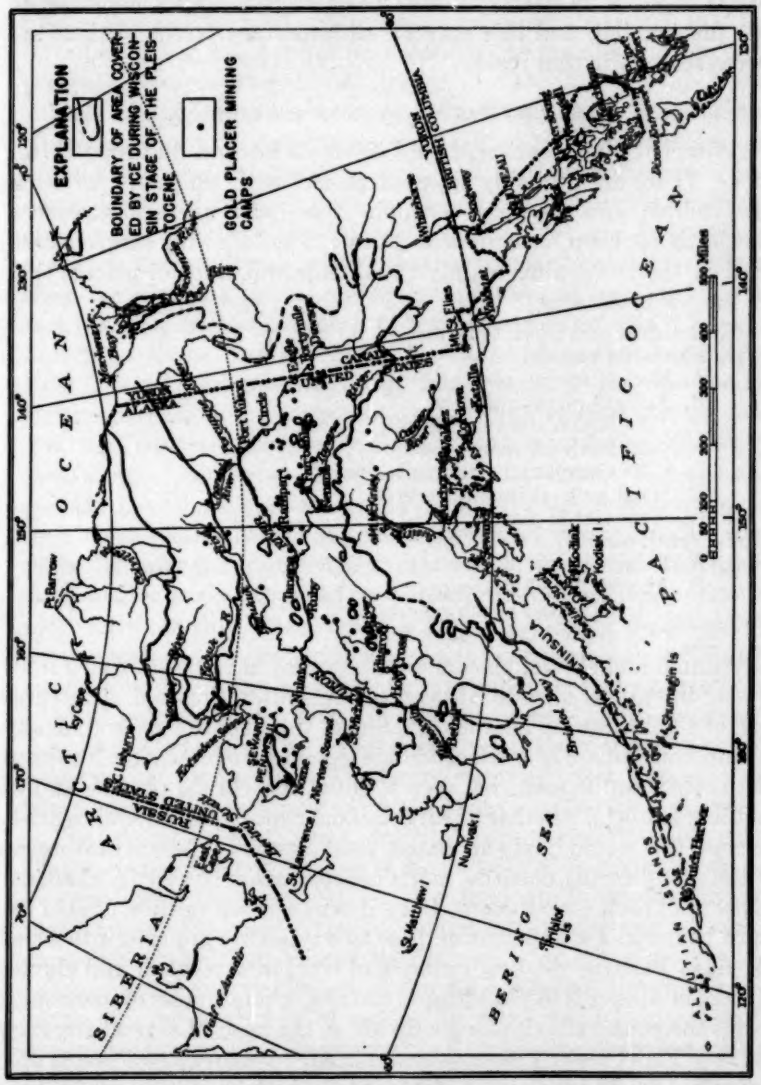


Fig. 5.—Localization of gold placers in unglaciated areas of Alaska.

eastern Alaska. On the other hand, the heavy cover of residual and eluvial deposits in interior Alaska has certainly been a handicap to lode prospecting, and this may be an important factor in their apparent scarcity in that region.

CLASSIFICATION OF GOLD PLACERS

A complete classification of gold placers is beyond the scope of this paper. There are probably types of placers with which the writer is not familiar, and there are certainly some, such as aeolian placers, that have not been recognized in Alaska. The following simple classification, therefore, aims mainly to tabulate the kinds of placers that are known in Alaska:

I. Residual and eluvial placers.
II. Fluviatile placers.
  A. Recent stream placers.
  B. Ancient stream placers.
    1. Bench stream placers.
    2. Buried stream placers.
    3. Compound stream placers.
  C. Hard rock sedimentary reefs.
III. Glaciofluviatile placers.
IV. Beach placers.
  A. Recent beach placers.
  B. Ancient beach placers.
    1. Elevated beach placers.
    2. Buried beach placers.

Residual and eluvial placers are those that have been formed in or almost in situ, as a result of deep residual alteration and disintegration of a gold-bearing bedrock. Placers of this type are geographically uncommon and are of small economic significance in Alaska. No sharp distinction can be made between residual and eluvial placers, and in fact it is doubtful whether a truly residual deposit can be said to exist, because this would imply an almost total absence of lateral movement of the gold-bearing detritus, and a concentration largely by chemical removal of rock constituents, and a downward segregation of gold toward bedrock. For this reason these two types are grouped into a single class. Perhaps the best example of combined residual and eluvial placers in Alaska is in the Iditarod district, where a mass of monzonite forms the country rock along a divide at the head of several streams, notably Flat Creek. This monzonite is cut by many small seams and stringers of gold-bearing quartz, some of which have been exposed by mining operations. At this locality deep residual alteration of the monzonite has taken place, and by the combined action of gravity, frost-thrusting, and ground water a great volume of loosened and dis-

integrated bedrock is slowly moving downhill into the adjoining valleys. Some of this material might possibly be classed as a residual placer, but another part, which has clearly migrated down the slopes of the ridge but has not yet been handled by running surface water, is a good example of an eluvial placer.

Most of the commercial placers of Alaska are of the fluviatile type. These have been divided upon the basis of their relative ages into present and ancient stream placers, but in this connection a sharp distinction must be made between the age of the present stream gravels, and the age of the alluvial gold contained in them. In speaking of southern Alaska, it was stated that sufficient time had not elapsed since the retreat of the ice for the present streams to erode from bedrock sources, and to concentrate workable gold placers. This is believed also to be true in interior Alaska, but postglacial and Recent time in Alaska are not necessarily synonymous terms, and the term Recent may connote a longer interval of time, at least at some localities, than the term postglacial. But a more important consideration is that a large volume of already disintegrated debris, and also older placers, have been continuously available to the Recent streams of interior Alaska, throughout their life history. Hence Recent placers do really exist in interior Alaska, though it is doubtful whether any considerable part of the gold contained in them was eroded from bedrock in Recent time. Recent placers must therefore be defined as placers in which the component gravels have been moved to their present sites during a single erosional cycle, controlled by a nearly static base level of erosion, and within the Recent epoch. Many examples of Recent stream placers could be cited, but their common occurrence renders this unnecessary. Generally speaking, the Recent stream placers are of less economic value than the older fluviatile placers.

The ancient stream placers consist of gold-bearing fluviatile gravels that were deposited during one or more cycles of erosion preceding the last one. Such placers are arbitrarily divided into bench and buried placers, upon the basis of the altitude of their underlying bedrock, as compared with the altitude of the bedrock lying below a body of adjoining stream gravels. Bench placers are commonly developed as the result of a renewed cycle of erosion, in which the local base level of erosion is lowered at a rate greater than the rate at which a stream can lower by erosion its preexisting valley floor. If this occurs, there will remain uneroded remnants of the old bedrock floor, covered by more or less alluvial material at altitudes appreciably higher than the bedrock and alluvium of the new valley floor. Such uneroded remnants of

auriferous alluvium constitute true bench placers. If, however, the rate of lowering of the local base level of erosion is equal to or less than the erosional rate of the stream, the older bedrock surface will be concurrently lowered and its overlying cover of alluvial material will be continuously reworked, in such a manner that neither bedrock nor alluvial terraces will be evolved. The same result more frequently materializes as a result of variable rates of the two functions, so that terraces have been formed and subsequently destroyed, leaving little or no trace of their former existence. In such cases the gold is really ancient bench gold, but the gravels now containing it are Recent placers. Similarly, however, the gold of the present bench placers may have rested temporarily for considerable periods in still older placers. Many splendid examples of true bench placers occur in the Fortymile district. On the other hand, Mastodon Creek, in the Circle district, is a good example of a valley in which the terraces were destroyed almost as fast as they were created.

Buried placers are those that resulted from an elevation of the local base level of erosion, or from other causes such as aeolian action, so that ancient auriferous gravels that formerly constituted a valley floor were progressively buried by a general alluviation. In a certain sense, all placers are buried placers because erosion in the headwater part of a valley can take place contemporaneously with alluviation in its lower stretches, even during an erosional cycle initiated by a lowering of the local base level of erosion. But the term buried placers is here used to designate gold-bearing alluvial deposits which were formed in an erosional cycle that antedated the cycle during which they were buried. Unlike bench placers, buried placers can not be simultaneously created and destroyed, for theoretically in the sites of buried placers, erosion of bedrock is nil, though it will continue to exist in the headwater parts of a valley unless or until aggradation reaches that far upstream. Some of the placers of the Fairbanks district are examples of buried placers, but for the most part they are more completely described as compound placers, because they have been materially affected by one or more erosional cycles that postdated their burial.

Compound stream placers comprise many gold-bearing alluvial deposits, which on geomorphic grounds could be divided into an almost endless number of species. The development of these subordinate types is a function of the number and character of the variations in the local base level of erosion, and also of the rate of change of such variations; and these factors, in turn, are functions of simpler ones,

which often are still too complex for simple exposition or analysis. The placers of the Livengood district, to take a relatively simple example, were at one stage in their development buried placers. As a result of an elevation of the base level of erosion, accompanied by extensive aggradation, Livengood Creek was superposed onto one side of its old valley wall. By a subsequent lowering of the base level of erosion, a new valley floor was carved contiguous to the old valley floor, but separated therefrom by a bedrock reef. Finally the new valley floor was so greatly eroded that the altitude of its bedrock floor became less than that of the old bedrock floor, whereupon the old buried placer came to have the general appearance of a bench placer. Similarly bench placers can be rebuilt to simulate simple buried placers; bedrock terraces may be evolved which are younger than their contiguous valley floors; and in the geologic interval ordinarily considered to comprise the geomorphic record, these and other anomalous processes may be several times repeated. Consequently compound stream placers are as difficult to classify as sedimentary rocks, and at present their characteristics are much less well known. Many of the ancient placers of interior Alaska are compound placers, but at few places have their complete histories been deciphered.

Alaska contains no auriferous hard-rock reefs of economic value, similar to the Witwatersrand deposits of South Africa. But Tertiary sedimentary rocks carrying sparsely disseminated gold, occur south of the Yukon River in a narrow belt extending from the international boundary west-northwest for more than 100 miles. The conglomerates that constitute a part of this sequence of rocks have clearly acted as a proximate source of the gold now contained in the bench and stream placers of this general district. This belt of Tertiary rocks is the best, though not the only, example of auriferous hard-rock reefs known in Alaska.

Glacial action tends to dissipate, rather than to concentrate, the heavy metals and minerals, but few glacial deposits are altogether free of the effects of running water. Some glaciofluviatile deposits, however, are fairly well sorted, and except for their original heterogeneity are not especially different from normal stream deposits. Hence if glacial and more particularly glaciofluviatile deposits were derived from a gold-bearing bedrock, and were not too far removed by glacial action from their original sources, the glacial dissipation of the gold might be small enough to render such deposits workable as placers. One of the best examples of a glaciofluviatile placer conforming to these conditions may be seen on Bird Creek, in the Cache Creek district.

If gold-bearing rocks occur close to a body of standing water large enough to produce marked wave action along its bounding beaches, gold placers may be formed by the sorting action of the waves. The formation of such beach placers, however, is often aided by the prior concentration of gold as fluviatile placers in valleys which discharged to the sea. Beach placers are known in Alaska at a number of localities, but the richest and best known of these are at Nome, bordering upon Norton Sound. Here are found Recent beach placers and ancient ones, the latter including both the elevated and the buried types.

The conditions at Nome can best be understood by visualizing a sloping foreland, with a width of more than 3 miles, which lies between low hills to the north and Norton Sound on the south. Within this foreland, the bedrock is covered by alluvial deposits ranging in thickness from 30 to 120 feet, and of these the lower few feet superjacent to bedrock are beach gravels, mainly of Pliocene age. The overlying deposits are both marine and terrigenous in origin, the terrigenous deposits lying for the most part closer to the hills. Starting 3 miles from the sea, a bedrock profile drawn southward toward the sea shows an initial altitude of about 70 feet above sea level, but passes below sea level about three-fourths of a mile north of the present beach. At the north end of this bedrock profile is a nearly vertical cliff, 12 to 14 feet high; and here there exists an alluvial cover about 85 feet thick, of which the lower 3 to 5 feet are Pliocene beach gravels, whereas the overlying material consists mainly of terrigenous deposits of Quaternary age. From the base of this cliff, bedrock slopes gently and gradually southward to and beyond the present strand line; and upon this sloping surface are a number of sites at which pronounced concentrations of gold were effected by an advancing Pliocene sea. Without citing the local names of these successive sites, it suffices to state that there are five such beaches on bedrock, of which the two most southerly, which lie below the present level of the sea, are the oldest; whereas the other three, which are above the present sea level, are progressively younger to the north, the youngest being at the base of the above-mentioned bedrock cliff. As the sea subsequently retreated, another auriferous beach was formed about half a mile from the sea, but not on bedrock; and finally, the present auriferous beach was built. From the fossil record, the sixth (non-bedrock) beach is also of Pliocene age, so that a long record of Pleistocene marine sedimentation appears not to be present in this area. This conforms with conditions found elsewhere along Bering Sea, which point to the presence of a strand line far seaward of the present strand line, during a large

part of Pleistocene time. From these general conditions, it is easily understood how and why there occur at Nome present, ancient elevated, and ancient buried beach placers.

BEDROCK SOURCES

The natural gold-silver alloys of Alaska are associated, either directly or indirectly, with granitic rocks, or with their surficial equivalents; and the general term granitic rocks is here used to include granite, monzogranite, quartz monzonite, granodiorite, and quartz diorite, together with their quartz-poor equivalents. Few if any quartz-free granitic rocks appear to be genetically associated with gold, but there are some, such as the monzonite at the head of Flat Creek, in the Iditarod district, that are distinctly low in silica.

Granitic rocks of several ages have been identified in Alaska. The oldest of these is a pre-Cambrian formation called the Pelly gneiss, which occurs in east-central Alaska and consists dominantly of massive augen gneiss grading into feldspathic quartz-mica schist. Cockfield,[15] of the Canadian Geological Survey, implies though he does not definitely state, that some part of the placer gold of the Sixtymile district, of Yukon Territory, is genetically related to the Pelly gneiss, but no evidence of such a relationship has so far been discovered in Alaska.

The granitic rocks of the Coast Range and the Alexander Archipelago of southeastern Alaska, of the coastal ranges of southern Alaska, of parts of interior Alaska, and of the Brooks Range of northern Alaska are considered to be mainly of Mesozoic age. It is believed, however, that these granitic rocks range in age from Middle Jurassic to Lower Cretaceous, being emplaced in more than one geologic epoch and probably in several stages. The granitic rocks of the Coast Range, according to Buddington,[16] consist principally of granodiorite, quartz monzonite, and quartz diorite, in the order named; but to the southwestward, in the Alexander Archipelago, the granitic rocks appear to be less silicic and may be somewhat older than those of the Coast Range proper. The granitic rocks of the coastal ranges of southern Alaska are also believed to antedate the granitic rocks of the main Coast Range, being probably of Middle Jurassic age. In interior Alaska, the Mesozoic granitic rocks include mainly quartz diorite and granite, with few intrusives of monzonitic character. They may be

[15] COCKFIELD, W. E. *Sixtymile and Ladue Rivers Area, Yukon.* Can. Geol. Surv. Mem. 123: 49. 1921.

[16] BUDDINGTON, A. F., and CHAPIN, THEODORE. *Geology and mineral deposits of southeastern Alaska.* U. S. Geol. Surv. Bull. 800: 177. 1929.

either of Jurassic or Cretaceous age, as the stratigraphic evidence of their geologic age is lacking. On rather insufficient data the granodioritic rocks of the Brooks Range are likewise considered to be either of Jurassic or Cretaceous age. Workable gold-bearing quartz veins and lodes of other types have been found in the vicinity of some of the Mesozoic granitic rocks, and to a greater extent where placers are not now present, than where they are. Such lodes appear to represent mainly the mesothermal type of mineralization.

The Tertiary period also was characterized by the intrusion of granitic rocks, in one or more stages of emplacement. Certain early Tertiary granitic rocks appear to be normal granite, quartz monzonite and quartz diorite, but another type believed to be of later Tertiary age are nearly everywhere quartz monzonite or monzonite, relatively low in free silica, and carrying pyroxene as the principal dark mineral. Such rocks are widely distributed in southwestern Alaska, and are rated as second in importance as producers of placer gold. Much mineralization has been found in and near the mid-Tertiary granitic rocks, in the vicinity of some of the derived placers, but few important lodes of this age have been discovered. In general, the gold occurs in small discontinuous quartz veins and stringers, which appear to represent fillings in shattered epithermal zones. Cinnabar is almost everywhere associated with the placer gold that has been derived from the mid-Tertiary granitic rocks, and some mercury lodes of this age have been successfully mined.

FORMATION OF PLACERS

Since most of the placers of Alaska are of fluviatile origin, and even the beach placers were in some measure concentrated as preexisting fluviatile deposits, the formation of placers deals mainly with the erosion of gold from bedrock sources, and its transportation and concentration by the action of streams.

Many data indicate that most of the placer gold of Alaska was liberated from its bedrock sources long before it was finally deposited in the placers that are now being mined. In other words, it is believed that much of this gold has been handled and rehandled by streams in many successive geomorphic cycles. In east-central Alaska, for example, the gold that originated in the Mesozoic granitic rocks south of the Yukon River, began to be freed from its bedrock sources when those rocks were first bared to erosion; and since a considerable part of the gold was deposited, and some of it still remains, in the early Tertiary conglomerates of this area, the long alluvial history of the

gold in this area is not open to question. At most localities, however, this generalization is not directly provable, though it is strongly suggested by the presence of large quantities of placer gold in certain localities where few or no evidences of mineralized bedrock can be found; by great differences in fineness between placer gold and the gold of geographically contiguous lodes; and in fact by the mere presence of deeply truncated laccoliths and stocks of granitic rocks in the drainage basins where workable placers occur. Naturally, since the parent rocks range in age from Middle Jurassic to mid-Tertiary, no generalized statement is possible regarding the ancient climatological conditions under which the country rock was first disintegrated and made available to stream action. But during some epochs, notably just before the general epeirogenic uplift at the end of the Pliocene epoch, a large volume of residual and eluvial material is believed to have mantled much of Alaska. In interior Alaska, for example, there are placer camps, as at Poorman, where practically all the gravels of the placers are vein quartz and chert. In such localities, it seems certain that the concentration of siliceous rocks is due to the disintegration and destruction of the other rocks with which they were originally associated. Probably, therefore, a large part of these siliceous gravels were derived from bedrock sources long before the Quaternary period.

In streams having gradients of the same order as those obtaining in the medial courses of the usual placer streams of interior Alaska, the downstream vector of movement for gold appears to be small. Splendid examples of this feature are apparent in Fourth of July, Coal, and Woodchopper Creeks, in east-central Alaska, where important placers have been concentrated from the above-mentioned Tertiary bedrock in the present valleys during several erosional cycles. The Tertiary rocks cross these three valleys as a belt several miles in width. Upstream from these gold-bearing rocks no placers exist, and downstream from them the workable placers terminate in a very short distance. The same feature may also be noted in Hunter and Little Minook Creeks, in the Rampart district, where the present placers have been reconcentrated from a belt of unconsolidated auriferous Pliocene gravels, that crosses the valleys of these two streams. Some of the very fine gold, of course, travels many miles downstream, and lodges in the large trunk valleys; but the amount appears to be very small in comparison with that which is repeatedly handed by streams in successive erosional cycles, and still remains in the original valleys where it was first concentrated.

Since most of the placers of interior Alaska are classified as compound types, no simple exposition of their general geomorphic history can be attempted; but it is relevant to review the classical hypothesis of their formation during a single cycle of erosion. (See Fig. 6.) In most small streams much of the alluvial material is in course of progressive movement from the headwaters downstream. In the uppermost stretches all this alluvium, from the surface to bedrock, at times of flood is moved downstream, and redeposited. But in most small streams there is a zone in the valley downstream from which the al-

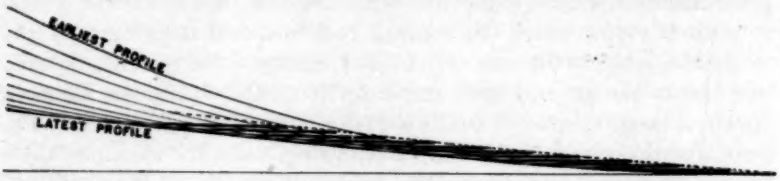


Fig. 6.—Successive longitudinal profiles of a valley, showing formation of a paystreak progressively upstream, with overlying alluvium omitted. (Vertical scale greatly exaggerated.)

luvial material on or near bedrock will not be further disturbed, even at the highest flood stages, unless the stream is rejuvenated by a lowering of its base level of erosion. The position and length of this critical zone varies with the strength of the current, the size and specific gravity of the alluvial materials, and with several other factors; yet its existence is fairly well substantiated. If a gold lode occurs at or near the head of a valley, the gold on being liberated by the process of weathering migrates downstream with the other stream detritus, gradually working its way toward bedrock. Somewhere in the critical zone, however, most of this gold, and all the coarse gold, finally comes to rest; and from this zone downstream the current of the stream is slower, and the detritus becomes thicker, so that the stream can no longer erode to bedrock. This critical zone, which lies between the headwater stretch of intermittent movement of all debris and the downstream stretch of no movement of the debris near bedrock, marks the downstream terminus of the paystreak; but the gold in process of downstream migration is also present upstream from the critical zone, and such gold may or may not constitute a paystreak, depending upon various factors. But stream erosion is a continuous process, in the course of which the valley is either extended backward into its divide; or, if another headwater stream is flowing in the opposite direction, the divide between the two streams will be lowered.

In either case, the net result is a change in the longitudinal profile of the stream bed, such that the headwater gradient is diminished and the critical zone of deposition migrates slowly upstream. Hence that stretch of gold placers, no longer subject to downstream movement, is lengthened, and a paystreak is deposited progressively upstream. The concept thus results that the part of a placer farthest downstream was deposited first and that the formation of the paystreak took place progressively upstream, as a series of overlapping wedges. This mode of paystreak formation is particularly applicable in areas where the local base level of erosion has remained sensibly constant over a long period of time; and such conditions have apparently obtained during certain erosional cycles in parts of interior Alaska.

If a paystreak was derived from a lode located in the headwater part of a valley, and if it was formed in the manner above outlined, it should be expected that most of the placer gold will be formed near, on, or in bedrock. This is actually true for most of the placer streams of Alaska, the gold being found in the lowermost few feet of gravel, on the surface of bedrock, and if the latter is greatly fractured to a depth of as much as 6 feet in bedrock. Some of the early dredge operators in Alaska failed to recognize the depth to which gold can penetrate in bedrock; and as a result of this, and also of inadequate washing in the trommel, some of the old dredging sites are now being reworked at a good profit. The absence of this localization of the gold becomes immediately a reason for searching a valley for uneroded lode sources not in the headwaters, or for postulating a rapidly changing local base-level of erosion during the deposition of the gold, or after a part of it had been deposited. One of the most striking examples of gold that is not concentrated near bedrock, is found in the placer streams which derived their gold from the Tertiary sedimentary reefs, above described.

It is obvious that this idealized mode of placer accumulation, which stresses the lack of geologic simultaneity in the formation of a paystreak, may be modified in many ways, not merely by a succession of erosional cycles, but also by conditions and events that may exist within a single cycle of erosion. The theory, as sketched, applies particularly to placers that accumulate from lodes that are localized in or near the headwater portion of a valley, and many examples of such conditions in interior Alaska could actually be cited. But the bedrock source of gold is not always thus localized, as for example where the locus of a lode system is more or less coincident with a valley, or where mineralized zones occur intermittently, crossing the

valley at different places. Likewise there may be present proximate sources of gold, other than bedrock gold, such as auriferous bench gravels of any origin, which are distributed along the sides of a valley, or auriferous gravels or conglomerates which cut across valleys. All such conditions, and combinations of them, tend either to modify or to render entirely inapplicable the idealized concept; and many such examples are known in interior Alaska where the general hypothesis does not apply, even within a single erosional cycle.

Summarizing, it needs to be stressed that no general hypothesis of placer accumulation can be presented. The volume of available debris, derivable from bedrock, is affected by climatological conditions, past and present; and such conditions also control the volume of water formerly, and at the present time, existing in valleys. The character of the alluvial deposits is likewise affected by climatological conditions, as for example in interior Alaska where these deposits are frozen to great depths. The velocities and erosive power of streams, on the other hand, are functions that depend upon many variables, among which are the volume of water, the transported load and the valley gradients. And finally, the valley gradients, though locally influenced by the character of bedrock and other factors, are in large measure controlled by the duration, changes, and accelerations in local base levels of erosion. Some of these data can be deduced or inferred from geologic studies; others can not. Hence, the history and mode of formation of placer deposits in a region constitute a series of individual, yet related problems, which are seldom completely solvable.

THE PROBLEM OF FINENESS

The fineness of lode and placer gold is an economic factor of considerable significance. Gold that is 900 fine, for example, yields a profit 20 percent greater than gold having a fineness of 750; and since many examples could be cited of finenesses of this order, the illustration is by no means overdrawn. In general, therefore, the matter of fineness has been approached from a purely economic rather than a genetic point of view; and thousands of assays have been made of Alaska gold, with few attempts to correlate and to understand these significant data.

The genetic problem of fineness has several aspects, of which the most general has to do with the range and limits of the ratios of gold to silver in all the natural alloys of these metals. A second phase of the problem is concerned with the recognition and explanation of variations in the grades of lode and placer gold, and this veers into

and is really a specialized part of the theory of placer genesis. Still another phase of the problem is what might be called a problem of fineness of lower magnitude, dealing with the variations in fineness within individual nuggets, grains, and crystallites of gold-silver alloys; and this in turn leads to a physical-chemical study of free gold.

It has already been shown that artificial alloys of gold and silver form a continuous series of solid solutions, with all possible compositions from pure gold to pure silver. The natural alloys of gold and silver, however, seldom contain more than 40 percent and never more than 60 percent of silver; whereas at the other end of the system, native silver is usually free of gold, and seldom contains more than traces of it. Therefore, it is possible that a miscibility gap exists in the solid state of the gold-silver system, as developed in nature. It has also been shown that the specific volumes of the natural alloys of gold and silver depart materially, and in a reverse manner, from the specific volumes of the corresponding artificial alloys. Hence, it appears doubtful that the natural gold-silver alloys are altogether solid solutions; or, if they are, the presence of a small percentage of base metals in the dross has produced some remarkable atomic readjustments. Moreover, since most geologists believe gold-quartz veins to be of hydrothermal origin, what basis is there for assuming that gold and silver will crystallize in the presence of silica, water, base metals, and mineralizers to produce a solid phase identical with that which solidifies from dry melts of gold and silver alone? And finally, is it not possible that allotrophic modifications of gold and silver may crystallize under the conditions of cooling formulated by geologists? These questions will be answered only by laboratory work on specimens of the natural gold-silver alloys; and such studies will probably have to include the investigation of many physical properties of such alloys, both on macroscopic and microscopic scales, in addition to chemical and thermal analyses.

High-grade placers can be developed by the partial erosion of high-grade lodes, thus making it possible to interpret preexisting bedrock conditions in the light of the present bedrock; yet this condition seldom obtains, because high-grade lodes are rare. On the other hand, high-grade placers may also be produced from low-grade lodes, but under such conditions the life history of the placers is so extended that the original lodes may be largely or completely removed by erosion. At some localities the roots or basal parts of the lodes may still remain, but the contained ores may be quite different from the medial and apical horizons that have been removed. Hence, it is

seldom that observations on bedrock lead to a complete understanding of the character and genesis of the preexisting ore deposits that served as the sources of the placers.

Few data have been collected in Alaska that bear upon the character of the eroded lodes, but one generalization has been adduced, partly from theoretical reasons and partly from observed relationships, that seems to bear upon the distribution of fineness in placers. It is probably the usual, rather than the unusual, condition for the fineness of gold to vary in different parts of a lode. Pertinent data on this point are lacking, partly because the depth of many gold mines is less than the thickness of rocks eroded to produce the present placers, and partly because this topic has not received the consideration it could have received in our deep mines. But since the primary ores of the precious metals are known in some mines to give place at depth to base ores, it is a reasonable hypothesis that free gold itself, in the apical horizons of an original ore body, may be of higher fineness than that which occurs at considerably greater depths, as a result entirely of hypogene processes. The apical enrichment of lode gold by supergene processes can hardly be questioned at some localities.

Gold lodes have been either wholly or partly eroded to produce their derived placer deposits. Let it be assumed that the apical portions of lodes contained gold of higher grade than the lower horizons. Then if they have been wholly eroded, and if no enrichment of the gold has occurred during or after the transformation of the lode gold to placer gold, the average fineness of the placer gold should equal approximately the average fineness of the preexisting lode gold. But if the lode deposit has been only partly eroded, as is usually true, then the average grade of the gold in any one paystreak should be higher than that of the gold in the uneroded part of its antecedent lode. Moreover, and regardless of the degree of erosion, it follows that the average fineness of all the gold recovered from existing lodes should be less than that of the average fineness of all placer gold; and this is actually true. It should also follow from these considerations that gold of lower grade could be found in existing lodes than in placers; and this is likewise true, as little or no gold having a fineness of less than 600 has been found in placers, whereas lode gold has been found to have a fineness as low as 400.

In addition to variations in the primary fineness of gold within a preexisting lode system, it is probable, at least in interior Alaska, that a zone of oxidation and enrichment has existed continuously from the

time that these lode systems were bared to erosion to the present day. If surficial enrichment within a lode system has operated to increase the fineness of lode gold, then in a country free from glaciation, this has been a continuous process to which all the lode gold was subjected, though perhaps in varying degrees, before it was liberated from its bedrock sources. This process of enrichment may, and in some areas certainly has, operated to produce marked differences in the grades of lode gold and placer gold derived therefrom; but unless this process varies greatly in intensity from one geologic epoch to another, it is improbable that it has been more than a minor factor in producing variations in the grade of the gold within any one paystreak.

One of the best examples known in Alaska of a great divergence between the lode gold and the placer gold derived from it, has been described by the writer[17] in the Nixon Fork district. Here occurs a quartz monzonite of Tertiary age, which has been the bedrock source for gold placers in the streams draining from it; yet the roots of the lodes are still preserved, and are being actively mined as gold lodes. From the records of thousands of ounces of this lode gold, its average fineness is known to be 735, with maximum and minimum values, respectively, of 781 and 715; yet in Hidden Creek, which drains out of the lode area, the maximum, minimum, and mean finenesses are, respectively, 961¾, 892½, and 928 parts gold in a thousand. It should be stressed also that at this particular site the fineness does not increase progressively downstream; and although most of the paystreak that has been mined is underlain by a bedrock of limestone, nevertheless this paystreak extends upstream into the zone of quartz monzonite bedrock. Certainly no better example than this could possibly be found to prove that the gold eroded from the apical part of this lode system was of higher grade than that now being mined in the roots of the lode; but such conditions indicate an enrichment of the alloy in gold in the zone of weathering, before it was liberated from its bedrock source. In other words, as no marked variation of fineness is known within the paystreak, this locality may not be cited as an example of primary differences in the grade of the lode gold.

The general accepted theory has been stated, which pictures the paystreak as a series of overlapping wedges of gold-bearing alluvium, which are progressively deposited upstream during a single erosional cycle. According to this view the downstream end of a paystreak is

[17] MERTIE, J. B., Jr. *Mineral deposits of the Ruby-Kuskokwim region, Alaska.* U. S. Geol. Surv. Bull. 864: 193–194, 229–242. 1934.

its oldest, and the upstream end is its youngest part, if the deposition has taken place during a single cycle of erosion. A hypothesis has also been stated, which assumes that the apical part of a gold lode contains gold of higher grade than its lower horizons. Taken together, these two concepts lead directly to the conclusion that the gold of highest grade is likely to be found in the downstream end of a paystreak, and that the grade of the gold may diminish progressively upstream. This relationship actually exists in some placer paystreaks in Alaska, but in others the fineness has been observed to change erratically, or not at all.

The progressive increase in the fineness of placer gold, in going downstream, has heretofore been explained as due to the removal of silver from gold-silver alloys as a result of solution by cold surface waters, during or after the formation of a paystreak. According to this hypothesis, the gold farthest downstream has traveled a greater distance from its parent lode than the gold farther upstream. Therefore it has suffered the most handling by streams, has been to the greatest degree comminuted, and for both these reasons has been the most vulnerable to solution, Also, it has been longest separated from a bedrock source, and for this reason, too, should have been most affected by solution. This hypothesis is further supported by an experiment performed by McConnell,[18] on some of the placer gold of the Klondike district, in Yukon Territory, Canada. He found that gold shaved from the outer surface of a nugget assayed 60 to 70 parts per thousand finer than gold from the inside of the nugget; and this has been generally accepted as a proof that surface waters dissolve an appreciable amount of silver from gold-silver alloys in a paystreak. Let us look at the supporting data.

It has already been shown that the silver contained in artificial alloys of gold and silver can be completely dissolved by strong inorganic acids, only when the ratio of gold to silver is 1:3 or less; also that if this ratio is greater than 1:1.5, corresponding to a fineness of 400 parts gold in a thousand, no silver will be dissolved. It has also been shown that the solubility of silver in pure water is very slight. But practically all placer gold is of higher grade than 600 fine, and moreover we are dealing with ordinary cold surface waters, instead of strong inorganic acids. Finally, it must be remembered that any gold that has remained undisturbed in the placer paystreaks of interior Alaska since the beginning of Pleistocene time has probably

[18] McConnell, R. G, *Report on the gold values in the Klondike high-level gravels.* p. 979. Geological Survey of Canada, 1907.

been entirely untouched by water for the last million years, because these alluvial deposits were then, as now, largely frozen.

Still other facts have to be considered. The assayer knows that even strong inorganic acids do not readily remove all the silver from large pieces of a gold-silver alloy; and for this reason, a sample of the alloy, after quartation, is hammered flat on an anvil before treatment with nitric acid, in order to present a large surface to solution. Hence, the weak solvents postulated to exist in cold surface waters should affect only the outer layers of grains of placer gold; and for this reason the surficial volume of nuggets and coarse grains of gold, in which solution of silver might occur, is a smaller proportion of the total volume than in small grains of placer gold. It, therefore, follows, insofar as enrichment by solution of silver is concerned, that nuggets and coarse grains of placer gold should be of lower grade than the finely comminuted grains of placer gold. Actually, in any one paystreak, and at any one place in the paystreak, the reverse is usually true. Furthermore, when any appreciable amount of silver is dissolved in the laboratory from a gold-silver alloy, the sample becomes distinctly porous; and if much of or all the silver is removed, the sample becomes very fragile and may even crumble to a powder. Therefore, if solution of silver is actually accomplished by cold surface waters to an extent sufficient to change appreciably the fineness of placer alloys, this process should be reflected in a marked surficial porosity. But this also has not been observed.

As for McConnell's experiment, nothing is proved except that the outer surfaces of certain nuggets were of higher grade than the inner parts. It does not at all follow that this relationship is due to solution of silver by cold surface waters, for either it may have been an original characteristic of the primary lode gold, or, more probably, it was caused by surficial enrichment in the zone of oxidation, long before the gold was liberated from its bedrock source.

As a result of these considerations, the writer is not disposed unreservedly to accept the idea of any progressive change of fineness in a placer paystreak, as a result of solution of silver from gold-silver alloys by the action of cold surface waters. But it must be admitted that the alternate hypothesis is also unproved. In the first place it rests upon another hypothesis regarding the vertical distribution of different grades of gold in preexisting and present lodes. And secondly, it rests upon physical-chemical data that assume an essential identity, or at least the great similarity, of artificial and natural alloys of gold and silver, in so far as their chemical reactions are concerned. Hence,

additional geologic, mining, and chemical data will be needed to prove or to disprove the hypothesis above outlined. If, for example, the emplacement of a granitic body long antedated the formation of its associated lode deposits, and if a period of diastrophism had intervened between these two processes, the apex of the intrusive mass and the apex of the mineralized zone would not necessarily correspond. And if diastrophism had occurred after either or both of these processes had occurred, the present cropping of an intrusive might correspond to neither of these antecedent apices.

Mining and chemical data are required, most of all to learn the three-dimensional variations in fineness that may exist in present gold lodes. Assays, both of bulk samples and of individual grains, should be made of uncontaminated samples of free gold taken from different horizons in lodes; and for this purpose assays of run-of-mine bullion may or may not suffice, depending upon the methods employed in recovering the gold. Assays, for example, of bullion recovered by cyanidization would certainly be useless. Complete chemical analyses should also be made, in order to learn the character and quantity of the metals in the dross; and for this purpose, even amalgamated free gold would not be serviceable.

Finally, the physical and physical-chemical properties of natural gold-silver alloys need to be studied, in order to learn how they differ from those of the corresponding artificial alloys. One of the most important problems of this work should be a complete physical and chemical examination of individual grains and nuggets of natural gold. According to Raydt's equilibrium diagram, it is possible, if the solidification of gold took place rapidly enough, that individual crystals of gold could be zonally grown, in the manner of the plagioclase feldspars. If this occurs, and if his equilibrium diagram applies to natural alloys, the outer zones of crystallites should be lower in gold than the cores. Such a condition could hardly influence materially the range of fineness in a placer paystreak, as it would be a microscopic phenomenon, of a lower order of magnitude. But the investigation of this and related phenomena is equally a part of the general problem of fineness.

CHEMISTRY.—*The fungistatic and fungicidal action of certain organic sulphur compounds.*[1] EDWARD L. EVERITT, Georgetown University School of Medicine, and M. X. SULLIVAN, Chemo-Medical Research Institute, Georgetown University.

Both bacteria and molds are in general useful to man, as for example in decomposing plant and animal debris, which, if allowed to accumulate, would sooner or later be to man's detriment. In both fields, certain forms have become parasitic on man or on the fruits of the field on which man depends directly or indirectly for food and clothing. The part that bacteria may play in the production of pathological condition has become common knowledge and has long been under study by the bacteriologist and the practitioner of medicine.

On the other hand, the relation of common molds to health and disease has been given less attention and study since, unlike the bacteria, molds do not in general cause acute and killing diseases, in man at least. However, Kuchenmeister (1857) lists 14 species of fungi that invade the skin, hair, nails, lungs, or mucous membranes. In the list are included *Tricophyton tonsurans*, which invades the hair follicles, and several species of *Aspergillus*, which infect the auditory duct, finger nails, toe nails, etc. Also ringworms caused by fungi of the *Tricophyton* or *Microsporum* families are often met with in man.

In medical practice attention is often called to Moniliae, fungi that invade the mucous membranes, especially of the mouth. Among the diseases of man attributed to this class of fungi are thrush and sprue. There is some suggestion also that fungi, at times at least, may be involved in such allergic conditions as asthma and hay fever. Thus, Prince, Selle, and Morrow (1935) report findings that indicate that molds may play a causative role in some cases of asthma and hay fever, while Brown (1936) considers that hypersensitiveness to fungi must take its place along with sensitization to pollens, animal epidermis, food, and bacteria in the causation of bronchial asthma, eczema, perennial hay fever, and other allergic conditions.

Since molds may destroy the necessary fruits of the field, causing rots of various kinds, and may also invade the skin, the hair, and lungs of man and are incriminated in certain forms of dermatitis, ringworms, actinomycosis of the lungs, loss of hair in some cases, and occasionally in certain allergics, whatever can be found about the metabolic processes and especially about means of preventing them

[1] The data in this paper are taken from the dissertation presented by Edward L. Everitt in partial fulfillment of the requirements for the degree of Doctor of Philosophy, Georgetown University, 1937. Received January 20, 1940.

from getting a foothold on plants, animals, or man would be decidedly worth while.

It is well known that molds and bacteria may be killed or inhibited in their growth by drying, heat, light, pressure, and by various chemicals. Chemical substances that kill are known as fungicides or bactericides, while those that simply inhibit growth are called fungistatic or bacteriostatic. Some of the chemical compounds used in the prevention of the growth of bacteria and molds are silver nitrate, mercuric chloride, iodine, phenol, cresol, benzoic acid, alcohol, and various simple sulphur compounds. Among the sulphur compounds used are carbon disulphide, hydrogen sulphide, sodium thiosulphate, flowers of sulphur, and colloidal sulphur. Lime and sulphur mixtures have been used for years to prevent the growth of fungi on plants and trees.

Our interest in the possibility of inhibiting the growth of molds that invade man was aroused by results obtained in a study of the changes brought about by certain wilt-producing organisms. In a study of acid-base and oxidation-reduction phenomena, it was noted that sodium thiosulphate added to the medium considerably reduced the growth of the molds. This finding suggested a trial of various organic sulphur compounds because elemental sulphur had long been in use in medical practice in ointments for eczema and various skin conditions and parasitic skin infections, and sulphur baths have long been believed to have medicinal value. A direct bearing on the relation of sulphur to fungi is the work of Lynch (1933), who reports the successful use of a sulphur ointment in the treatment of an *Aspergillus* infection in a scalp lesion caused by the bite of the red bug (*Leptus*), and the review of Roark and Busbey (1935), who list a number of organic sulphur compounds of high value as insecticides.

As pointed out by Roark and Busbey, sulphur in various forms and combinations is one of the most valuable and widely used insecticides and fungicides. In the form of elemental sulphur it is applied to fruit trees and ornamental plants both as a dust and in suspension in water for combating red spiders and fungous diseases.

We had on hand a large number of organic sulphur compounds made or secured in a general study of the relation of sulphur and sulphur compounds to health and disease. Some of these we hoped would be of value in medical and agricultural practice.

Accordingly, some 50 sulphur compounds were tested for their fungicidal action in vitro. The molds used were *Fusarium oxysporum* and *F. lycopersicum*, which cause, respectively, wilt of potato plants and tomato plants; *Aspergillus fumigatus*, which invades the ear of

man and occasionally the lungs; *Aspergillus niger*, which spoils foodstuffs and like *fumigatus* may invade man; and the *Penicillium* of Fleming, which according to Reid (1935) generates a material toxic to bacteria. The culture media used and the procedure employed for testing the inhibitory action of the various compounds are detailed in the following sections.

The culture medium—The synthetic culture medium used in this investigation was the same as used by Anderson, Everitt, and Adams (1933) in their study of the carbohydrate metabolism of *Fusarium oxysporum*, which causes wilt of potatoes. It was first used by Tochinai (1920) to study the carbohydrate metabolism of *Fusarium lini*. The composition of the medium is as follows:

Ammonium nitrate	1.00 gm
Magnesium sulphate	0.25 gm
Monopotassium phosphate	0.50 gm
Glucose	20.00 gm
Water to make	1,000 cc

In the present work, to 100-cc portions of this culture medium in 250-cc Erlenmeyer flasks various quantities of the organic sulphur compounds were added, and the flasks were plugged with cotton and sterilized at 15 pounds pressure for 20 minutes. Control flasks containing the medium without addition of the sulphur compounds were sterilized in a similar manner.

Inoculation of the medium.—The stock medium for the development of the molds was Sabouraud's dextrose agar described in Difco Manual, ed. 5, 1935. Spores collected from the agar slants were suspended in sterile distilled water, and 1 cc of the spore suspension was added to each culture flask by means of a sterile pipette. The sulphur compounds tested are listed in Table 1.

Compounds (1)–(13) were obtained from Dr. H. L. Haller, Bureau of Entomology and Plant Quarantine, U. S. Department of Agriculture. The remaining compounds were at hand at Georgetown University.

Inasmuch as most of these compounds were ineffective, that is, did not inhibit the growth of the molds, the formulas are not given here. Those compounds that were effective will be discussed in detail and their formulas will be given later.

With *Fusarium oxysporum* and *F. lycopersicum* used as test fungi, only a few of the compounds listed in Table 1 inhibited or stopped growth. The inhibitors were Nos. (10), (11), (33), (34), (36), and (47). These compounds inhibited growth for a period varying from 4–15 days, after which time the organism slowly developed. These compounds could be utilized as fungistatic material and might have application in medical practice, in external application. One compound, (24), the disulphide of ortho-thioaminophenol, absolutely prevented growth of *Fusarium oxysporum* but allowed a slight and

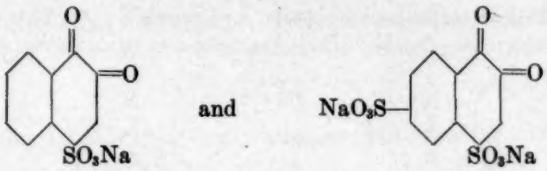
delayed growth of *Fusarium lycopersicum* with increase in growth after the nineteenth day. Colloidal sulphur, (33) (sulphur diasporal), was labeled as containing 10 mg of S in 2 cc. One cc was added to 100 cc of the culture medium. Colloidal sulphur (sulisocol) was labeled as 2 cc containing 20 mg of sulphur. One-half of 1 cc was added to 100 cc of culture media. Both types of sulphur in a colloidal complex markedly inhibited the growth of the molds, even at concentrations calculated to be 50 mg per liter. Since a question arose

TABLE 1.—SULPHUR COMPOUNDS STUDIED FOR FUNGICIDAL AND BACTERICIDAL PROPERTIES.

(1) Phenothiazine-6-carboxylic acid chloride
(2) 6-Acetyl-phenothiazine
(3) Phenothioxine
(4) Phenothiazine
(5) Tetrathiopentone
(6) Cuprous methylxanthate
(7) Cuprous isoamylxanthate
(8) Chlorbenzoketothiazine
(9) 4-Chloro-2-nitrophenyl thioglycolic acid
(10) Phenyl thioarsenite
(11) 4-Chloro-2-nitrophenyl sulphur amine
(12) 4-Chloro-2-nitrophenyl sulphur bromide
(13) Bis(2-nitrophenyl) disulphide
(14) Thioacetamide
(15) Mercaptobenzothiazole
(16) Phenylbenzothiazole
(17) Sodium diethyldithiocarbamate
(18) Diethyl thiourea
(19) Thiourea
(20) Disulphide of thiotyrosine
(21) Dithiosalicylic acid
(22) Phenylthioglycolic-ortho-carboxylic acid
(23) Benzidine sulphonate
(24) Disulphide of ortho-thioaminophenol
(25) Cysteic acid
(26) Thiazolidine carboxylic acid
(27) Formyl-dl-cystine
(28) S-carboxymethyl-cysteine
(29) Cystineamine hydrochloride
(30) Thiazolidine hydrochloride
(31) Thiobarbituric acid
(32) Benzyl disulphide
(33) Colloidal sulphur (diasporal) 2 cc = 10 mg
(34) Colloidal sulphur (hyposols or sulisocol) 2 cc = 20 mg
(35) Sulphanilic acid
(36) 1,2 Naphthoquinone-4-sodium sulphonate
(37) 1,2 Naphthoquinone-4-6-sodium disulphonate
(38) Sodium alizarine sulphonate
(39) Tropaolin 000
(40) Congo red
(41) Bromcresol green
(42) Methyl orange
(43) Cresol red
(44) Bromphenol blue
(45) Strychnine sulphate
(46) Thymol blue
(47) Prontylin (Winthrop)
(48) Trional
(49) Sulphonal
(50) Cystine
(51) Sulpharsphenamine

as to whether the inhibiting action was due to the sulphur as such or to the changes in the reaction of the medium, the study of the inorganic sulphur in the protective colloid solution was put aside for later development. Two compounds, mercaptobenzothiazole and phenylbenzothiazole, allowed no growth whatsoever of the two molds mentioned above when present in the culture media at the concentration of 5–10 mg in 100 cc of solution. Because a number of the organic sulphur compounds were found effective in inhibiting or utterly preventing the growth of the two molds, the experiment was extended to other molds as given in Table 2.

An interesting effect of chemical constitution on the growth of the molds was exhibited by compounds (36) and (37), namely, 1, 2 naphthoquinone-4-sodium sulphonate and 1, 2 naphthoquinone-4-6-sodium disulphonate, with the formulae—



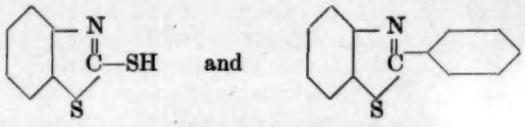
The 1, 2 naphthoquinone-4-sodium sulphonate had marked power of inhibiting the growth of the molds, while the 1, 2 naphthoquinone-4-6-sodium disulphonate was an excellent stimulator of growth. These findings are in harmony with the early work of Ehrlich and Herter (1904), who found the sodium salt of the 1, 2 naphthoquinone monosulphonic acid to be toxic. Since these compounds are relatively expensive and since the work of Ehrlich and Herter, especially that of Herter (1905), indicated that the 1, 2 naphthoquinone-4-sodium sulphonate was toxic to animals, no further attention was given to the compounds as fungistatic or fungicidal substances for use in medical or agricultural practice.

Of the compounds studied in relation to the growth of the molds in vitro,

TABLE 2.—STUDY OF THE MOST PROMISING SULPHUR COMPOUNDS HAVING FUNGISTATIC AND FUNGICIDAL PROPERTIES WHEN ADDED TO 100-CC CULTURE MEDIUM.

Compound No.	Amount used	F. oxysporum	F. lycopersicum	A. niger	A. fumigatus	Penicillium of Fleming
10	mg 12.5	First growth in 15 days, slow thereafter	No growth in 25 days	No growth in 11 days, slight in 25 days	No growth in 15 days, slight in 25 days	Very few spores in 15 days, slow thereafter
11	12.5	First growth in 15 days	First growth in 15 days	No growth in 11 days, slight in 15 days	No growth in 25 days	A few spores in 15 days, slight thereafter
15	3.0	Growth in 8 days, becoming heavy	Slight growth in 8 days, becoming heavy	Good growth in 8 days, very few spores	No growth in 25 days	Very slight growth in 25 days
15	5.0	No growth at any time	No growth at any time	Slight growth in 8 days, no spores	No growth in 25 days	No growth in 15 days, a few spores in 25 days
15	10.0	No growth	No growth	No growth	No growth	No growth
16	3.0	Slight growth in 8 days, becoming heavy	Slight growth in 8 days, becoming heavy	Heavy growth in 8 days, with spores	Slight growth in 11 days, slowly increasing	Slight growth in 8 days
16	5.0	No growth	No growth	Slight growth in 8 days	No growth in 25 days	Slight growth in 8 days
16	10.0	No growth	No growth	No growth in 25 days	No growth	No growth in 25 days
36	12.5	No growth in 11 days, some spores in 15 days, slowly increasing	No growth in 25 days	Good growth in 8 days	No growth in 25 days	No growth in 15 days, slight growth and a few spores in 25 days
47	10.0	Slight growth in 4 days	Slight growth in 8 days			
47	25.0	No growth in 4 days, slight growth in 12 days	Slight growth in 7 days	Slight growth in 7 days	Slight growth in 7 days	

number (15), mercaptobenzothiazole, and number (16), phenylbenzothiazole, were the most effective. Their chemical constitution, respectively, is—



Of these two, mercaptobenzothiazole was on hand in plentiful supply, so some attention was paid to it from chemical and clinical viewpoints and to its possible toxicity toward animals. As may be seen from its formula it is an organic sulphur compound containing nitrogen and an (SH) group. This compound, which is cheap and readily available, was first made by Hofmann (1887) and has been used in the rubber industry as an accelerator of vulcanization for a number of years. Its use for such purposes seems to have been first suggested by Bedford and Sebrell (1921). It is soluble in alcohol, chloroform, and benzol but is not very soluble in water. It is sufficiently soluble in water, however, to be used as a germicide. It is more soluble as a sodium salt and is rather soluble in sodium bicarbonate.

As judged by lack of growth for 50–60 days in the case of *F. oxysporum*, *F. lycopersicum*, and *A. fumigatus*, the compound has marked fungicidal power. In the case of *A. niger* and *Penicillium* of Fleming, mercaptobenzothiazole showed strong fungistatic activity, since no growth occurred until after a period of 25 days. Without prejudice as to whether a compound can be found that is fungistatic or fungicidal toward molds in general, it can be said that with the molds studied by us mercaptobenzothiazole had marked fungicidal or fungistatic activity.

Roark and Busbey (1935) state that mercaptobenzothiazole in concentration of 0.01 to 0.10 percent was effective in controlling a fungus living on wood and that it has been used in controlling aphids and mosquito larvae. Davis (1930) reported that this compound had little if any toxicity. He injected an aqueous solution of it into guinea pigs and a total injection of 14.5 mg in 20 days did not produce any injurious effects on the animals. Medical examination of the men working with mercaptobenzothiazole over a period of years in the Goodyear Tire & Rubber Co. did not show any toxic conditions or dermatoses. In a recent personal communication, Dr. Davis (1939) reiterates the conclusion that the compound has shown no toxic action on men working with it in the vulcanization of rubber.

We have given 20–100 mg of the mercaptobenzothiazole by mouth to guinea pigs weighing 400 grams with no gross evidence of toxicity and have injected 20 mg in aqueous suspension intraperitoneally into a 200-gram guinea pig with no effect on his activity, appetite, or general well-being. Dr. William B. Wardrop, of Washington, D. C., found the mercaptobenzothiazole practically as effective toward "athlete's foot" as salicylic acid. The var-

ious sulphur compounds were also tested for their bactericidal and bacteriostatic properties. The findings will be detailed in a subsequent paper.

SUMMARY

About 50 organic sulphur compounds were tested for their fungistatic and fungicidal action.

The molds used were the wilt-producing *Fusarium oxysporum* and *F. lycopersicum*, the pathogenic *Aspergillus fumigatus*, the common *Aspergillus niger*, and the *Penicillium* of Fleming.

Fungistatic activity was manifested by phenylthioarsenite, 4-chloro-2-nitrophenyl sulphur amine, 1, 2 naphthoquinone-4-sodium sulphonate, and prontylin or sulphanilamide.

Fungicidal activity was manifested by mercaptobenzothiazole and phenylbenzothiazole.

The most effective compound was mercaptobenzothiazole, which inhibited the growth of the molds in concentration of 50 to 100 parts per million. This compound is cheap and readily available.

The investigation deals only with in vitro tests, and no conclusion can be drawn as yet as to the therapeutic application of the various compounds. Preliminary toxicity tests on guinea pigs with both oral and intraperitoneal application indicate that mercaptobenzothiazole, the most effective fungicidal compound, has little if any toxicity.

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PALEOBOTANY.—*Additions to the Pensauken flora.*[1] EDWARD W. BERRY, Johns Hopkins University.

In 1935 the writer in collaboration with Alfred C. Hawkins published[2] an account of the plants found in the Pensauken formation in Middlesex County, N. J. From time to time Dr. Hawkins has sent in small amounts of additional material, which I have not had time to study thoroughly until the past summer. The material is in the same limonitic, coarse, micaceous sandstone as the original specimens, and the preservation of the plants leaves much to be desired in the way of details of venation.

The forms identified in the later collections are the following: *Cebatha carolina, Epigaea repens, Fagus americana, Nyssa sylvatica, Salix humilis,* and *Viburnum alnifolium.* Among these the *Epigaea, Fagus,* and *Nyssa* are additions to the Pensauken flora. They add little in the way of interpretive evidence of Pensauken time.

Epigaea repens Linnaeus

A single relatively small leaf, very coriaceous and with the margins inclined to be revolute. So far as I know the trailing arbutus has not heretofore been found fossil. In modern times its range is from Newfoundland to Florida in the Coastal Plain, usually on sandy soil. It occurs also beyond the limits of this province.

Fagus americana Sweet

This species, represented by leaves or fruits, is exceedingly abundant in the Pleistocene of southeastern North America, having been recorded from 11 States from Massachusetts on the north to Mississippi on the south, chiefly in river terraces in the Coastal Plain province, although also recorded from cave deposits in Pennsylvania and interglacial deposits in West Virginia.

Nyssa sylvatica March

A typical leaf of this species. Stones of this species have been recorded from the Pleistocene of both Maryland and the District of Columbia. In the modern flora it ranges, in rich, mostly swampy soil, from Maine and Ontario to Florida and Texas.

There is some confusion among our recent species as well as among the Pleistocene records. Two species, *Nyssa caroliniana* Poir and *Nyssa uniflora* Walt., are recorded from the Bridgeton sandstone of southern New Jersey and stones referred to *Nyssa biflora* have been recorded from the Pleistocene of New Jersey (Fish House), Maryland, Virginia, North Carolina, and Alabama. Probably some of these should really be referred to *Nyssa sylvatica.*

[1] Received October 11, 1939.

[2] BERRY, EDWARD W., and ALFRED C. HAWKINS, *Flora of the Pensauken formation in New Jersey.* Bull. Geol. Soc. Amer. 46: 245–252. 1935.

BOTANY.—*A nomenclatorial note on* Pseudoperonospora.[1] G. R. HOERNER, U. S. Bureau of Plant Industry. (Communicated by JOHN A. STEVENSON.)

Miyabe and Takahashi,[2] in describing a new species reported for the first time on hops, state:

> This fungus with its dichotomously branched conidiophores and with its conidia germinating by zoospores shares the characters of two genera *Peronospora* and *Plasmopara*, and may form an intermediate genus together with the downy mildew fungi of cucumber and *Celtis*. In 1901, Berlese[3] created a new subgenus, *Peronoplasmopara*, in the genus *Plasmopara* and placed under it *Peronospora cubensis* Berk. et Curt., and *Peronospora Celtidis* Waite. Rostowzew[4] reported in 1903 a detailed account of his study of different species of the Peronosporaceae, but especially of *Peronospora cubensis* B. et C., on which he founded a new genus *Pseudoperonospora*, apparently without knowing the above mentioned work of Berlese.
>
> In 1904, Clinton[5] made a critical study of the cucumber mildew and came to a similar conclusion in regard to the recognition of its generic position. But regarding Berlese's subgenus, *Peronoplasmopara*, because of priority of publication, and also because it was given definite descriptive characters as deserving preference over Rostowzew's rather indefinite *Pseudoperonospora*, Clinton elevated *Peronoplasmopara* to generic rank and included under it two species, *Peronoplasmopara cubensis* (Berk. et Curt.) Clint., and *Peronoplasmopara Celtidis* (Waite) Clint.
>
> In the present paper, we have adopted Clinton's view and name our fungus *Peronoplasmopara Humuli* Myb. et Tak., thus adding another species to this interesting genus.

However, on the basis of priority, if present generally accepted rules of nomenclature are followed, it appears that Rostowzew's name for the genus is still valid. In view of the characteristics assigned to the genus *Pseudoperonospora* and the validity of this genus name, it seems necessary to assign this generic designation to three species that have not hitherto been transferred to it although they clearly belong there. The following new combinations are therefore proposed:

Pseudoperonospora cannabina (Otth), n. comb.

Peronospora cannabina Otth, Mitt. Naturf. Ges. Bern, 1868, pp. 37–38. 1868.

Peronoplasmopara cannabina (Otth), Peg. Atti Accad. Naz. Lincei **114** (ser. 5, 26): 620. 1917.

[1] Technical Paper No. 327, Oregon Experiment Station. Received December 21, 1939.

[2] MIYABE, K., and TAKAHASHI, Y. Trans. Sapporo Nat. Hist. Soc. 1: 153. 1905–1906.

[3] BERLESE, A. N. Riv. Pat. Veg. 9: 123–126. 1901.

[4] ROSTOWZEW, S. J. Flora 92: 405–430. 1903.

[5] CLINTON, G. P. Rpt. Connecticut Agr. Exp. Sta. 1904: 329–362. 1905.

Pseudoperonospora elatostemae (Togashi and Onuma), n. comb.

Peronoplasmopara elatostemae Togashi and Onuma, Bull. Imp. Coll. Agr. and For. Morioka 17: 2, fig. 1. 1934.

Pseudoperonospora portoricensis (Lamkey), n. comb.

Peronoplasmopara portoricensis Lamkey, *in* Stevens, Mycologia 12: 52. 1920.

PROCEEDINGS OF THE ACADEMY AND AFFILIATED SOCIETIES

THE ACADEMY

358TH MEETING OF THE BOARD OF MANAGERS

The regular monthly meeting of the Board of Managers of the Academy was held in the Holmes Room of the Cosmos Club, January 12, 1940. In addition to the customary reports of the standing committees the Treasurer presented and discussed an epitome of his annual report. He showed that despite the publication of the "Red Book" the balance for the year's operations is only slightly red.

The report of the special Committee on Clerical Assistance for the Board of Editors, of which JOHN A. STEVENSON was chairman and H. E. EWING and HERBERT FRIEDMANN members, was read by Secretary N. R. SMITH in the absence of the committee. The report recommended discontinuance of the title "Editorial Assistant" but expressed no opinion on the question as to whether the Board of Editors should be granted or denied assistance. Following a general discussion on the advisability of permitting the editors to employ clerical assistance, the report was accepted.

The Custodian of Publications, W. W. DIEHL, presented a request from the Peiping National Library for a free subscription to the JOURNAL for the current year. This institution pleaded that the continued hostilities in China which had driven it to Yunnan made it impossible to renew its subscription. The Board instructed the custodian to grant the request for the year 1940.

The subcommittees on awards of Certificates of Merit for scientific achievement reported as follows:

E. A. GOLDMAN, chairman of the Committee for the Biological Sciences, presented the decision of his committee, which selected HERBERT FRIEDMANN to receive the Award for Achievement in the Biological Sciences for his work on the parasitic cowbirds and cuckoos and for his studies of avian taxonomy and geographic distribution. Dr. Friedmann was born in New York City on April 22, 1900. He received his B.S. degree from the College of the City of New York in 1920 and his Ph.D. from Cornell University in 1923. After a three-year National Research Council fellowship he taught first at Brown University, then at Amherst College. In 1929 he succeeded Robert Ridgway as curator of birds in the U. S. National Museum, a position he still holds.

H. L. CURTIS presented the decision of the Committee on the Engineering Sciences, of which he was chairman. For the award in this field PAUL ALBERT SMITH was selected for his contributions to topographic surveys of the ocean bottom along the eastern coast of the United States. Mr. Smith was born at Rising Sun, Iowa, January 9, 1901. He received his B.S. degree at the University of Michigan in 1924. In August 1924 he joined the staff of the U. S. Coast and Geodetic Survey and has remained with that organization.

H. D. MISER presented the decision of the Committee for the Physical Sciences, of which J. F. COUCH was chairman. For this award WILMOT HYDE BRADLEY was selected for his investigations of varves in the Green River formation of Wyoming and his contributions to the geology of abyssal sediments. Dr. Bradley was born at New Haven, Conn., April 4, 1899. He received his Ph.B. degree at Yale University in 1920 and his Ph.D. in 1927. During his summer vacations he worked as field assistant in the U. S. Geological Survey, and at the completion of his academic work he joined the staff of that organization, where he has remained.

After a discussion of the age limit, in which it was agreed that investigators eligible for honors are those who have not attained their forty-first birthday at the close of the year for which the awards are made, the Board voted without division to award Certificates of Merit to the above three nominees. Following a brief consideration as to how the Certificates evidencing this honor accorded by the ACADEMY were to be presented—which was without conclusion—the Board adjourned to resume its discussions informally over a surprise buffet supper provided by the retiring President.

The attendance of Board members follows:

Present		*Absent*	
C. E. CHAMBLISS	(Pres.)	O. S. ADAMS	(Rec. Sec.)
N. R. SMITH	(Corr. Sec.)	J. F. COUCH	(Board Member)
H. G. AVERS	(Treas.)	NEIL M. JUDD	(Board Member)
F. G. BRICKWEDDE	(Board Member)	H. C. FULLER	(Board Member)
J. H. HIBBEN	(Board Member)	H. S. GRAVES	(nonresident V.P.)
G. STEINER	(Board Member)	R. B. SOSMAN	(nonresident V.P.)
HENRY B. COLLINS, Jr.	(An)	W. B. BELL	(B)
A. WETMORE	(G)	B. H. NICOLET	(C)
H. D. MISER	(Gl)	A. H. CLARK	(En)
W. A. DAYTON	(F)	FRED O. COE	(M)
H. L. CURTIS	(Ee)	ALLEN C. CLARK	(H)
H. L. WITTEMORE	(Me)	G. F. GRAVATT	(B)
E. W. PRICE	(Hl)	ALEŠ HRDLIČKA	(An)
F. D. ROSSINI	(Sr. Ed.)	P. C. WHITNEY	(E)
W. W. DIEHL	(Custodian)	L. A. ROGERS	(Ba)
		WM. BOWIE	(Ml)
		J. H. DELLINGER	(R)

In addition to the above members there were present by invitation F. M. SETZLER, chairman of the Meetings Committee; E. A. GOLDMAN, chairman of the Subcommittee on Awards for the Biological Sciences; and the editors, C. L. GAZIN and J. H. KEMPTON.

SCIENTIFIC NOTES AND NEWS

The Department of State has notified the ACADEMY that the Eighth American Scientific Congress will be held in Washington, D.C., from May 10 to 18, 1940, under the auspices of the United States Government. The Secretary of State has appointed an organizing committee composed of government officials and distinguished scientists. Dr. ALEXANDER WETMORE, Assistant Secretary of the Smithsonian Institution, is the Secretary General of the Congress and the Secretary of the Organizing Committee. The Congress will be divided into 11 sections covering the various disciplines. The chairmen of these sections are as follows:

1. *Anthropological Sciences.*—HERBERT J. SPINDEN, Brooklyn Museum.
2. *Biological Sciences.*—EDWIN G. CONKLIN, Princeton University.
3. *Geological Sciences.*—T. WAYLAND VAUGHAN, Geological Society of America.
4. *Agriculture and Conservation.*—HUGH M. BENNETT, U. S. Soil Conservation Service.
5. *Public Health and Medicine.*—THOMAS PARRAN, U. S. Public Health Service.
6. *Physical and Chemical Sciences.*—LYMAN J. BRIGGS, National Bureau of Standards.
7. *Statistics.*—STUART A. RICE, Central Statistical Board.
8. *History and Geography.*—CLARENCE H. HARING, Harvard University.
9. *International Law, Public Law, and Jurisprudence.*—JAMES BROWN SCOTT, Carnegie Endowment for International Peace.
10. *Economics and Sociology.*—HAROLD G. MOULTON, Brookings Institution.
11. *Education.*—NICHOLAS MURRAY BUTLER, Columbia University.

Obituary

HARVEY (WILLIAMS) CUSHING, master-surgeon, neurologist, physician, critical investigator, medical bibliophile, inspiring teacher, littérateur, artist, died at New Haven, Conn., on October 7, 1939. Born in Cleveland, Ohio, on April 8, 1869, the ninth child in his family, he became the fourth in a line of doctors.

From school in Cleveland he went to Yale College (A.B., 1891) and then to the Harvard Medical School (A.M. and M.D., *cum laude*, 1895). After a surgical internship at the Massachusetts General Hospital, he went to Baltimore in 1896 as junior assistant in the surgical service of Halsted at Johns Hopkins Hospital. During 1900–1901 he studied abroad under Kocher and Kronecker in Berne, Mosso in Turin, and Sherrington in Liverpool.

After his return to Baltimore Dr. Cushing became neurosurgeon and then associate professor of surgery at Johns Hopkins. In 1912 he went to Boston as Mosley professor of surgery at Harvard and surgeon-in-chief to the Peter Bent Brigham Hospital. From 1915 to 1919 he saw service in France, during which time he became senior consultant in neurosurgery of the American Expeditionary Forces. Upon reaching the hospital retirement age of 63 in 1932, Dr. Cushing gave up his work in Boston and accepted appointment as the Stirling professor of neurology at Yale, which chair he held from 1933 to 1937.

Dr. Cushing's writings, as compiled at the time of his seventieth birthday, number 318 items, largely in the fields of neurosurgery, neurophysiology, endocrinology, and medical history. He was perhaps more widely known as the author of the Pulitzer prize winner *The Life of Sir William Osler* (1925).

Dr. Cushing was a member of many scientific societies and served as president of the American Society of Clinical Surgery (1921), the American College of Surgeons (1922), the American Neurological Association (1923), and the American Surgical Association (1927). Honors came to him in profusion, culminating in 1938 with the degree doctor of science, "honoris causa," from Oxford.

With Dr. Cushing surgery of the brain became for the first time scientifically established. By nature he was a perfectionist, and his accomplishments seemed to flow from his extraordinary capacity for sustained work. Of him truly it may be said that he was in all that he attempted greatest of the great.